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The effect of nanoparticles added to heated micropolar fluid

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ABSTRACT

This paper presents an analysis of momentum, angular momentum and heat transfer during the unsteady natural convection in micropolar nanofluids. Presented phenomena are modelled in the vicinity of a vertical plate and heat flux which rises suddenly at a given moment, using the boundary layer concept. Differential equations of angular momentum conservation are used according to the theory of micropolar fluids developed by Eringen. Finite difference method is used to solve the equations for conservation of mass, energy, momentum and angular momentum. Selected nanofluids treated as single phase fluids contain small particles with diameter size $d = 10$ nm and $d = 38.4$ nm. In particular, two ethylene glycol based nanofluids and one water-based nanofluid are analysed. Volume fraction of these solutions is 6%. First ethylene glycol solution contain Al_2O_3 nanoparticles (d = 38.4 nm), and the second ethylene glycol solution contained Cu nanoparticles ($d = 10$ nm). Water based nanofluid contain Al_2O_3 nanoparticles ($d = 38.4$ nm). As a result of solving conservation equations, unsteady velocity field (U, V), temperature (T), micro-rotation component normal to (x, y) plane (N), velocity gradient $\partial U/\partial Y$ and temperature gradient $\partial T/\partial Y$ are obtained. These results are compared to theoretical and experimental results presented in literature. At the end of this paper, heat transfer enhancement for analysed nanofluids is estimated.

1. Introduction

Over the last two decades a new generation of heat carriers known as nanofluids has been analysed [1–5]. These types of fluids consist of conventional fluid and nanoparticles with diameter of particle between 10 and 100 nm mixed uniformly with fluid. Generally, they contain particles of substances such as metal oxides Al_2O_3, TiO_2, CuO, ZnO and metals Cu, Au, Ag, Fe [1,2,5]. The discussed nanofluids are characterized by increased effective thermal conductivity and dynamic viscosity. During experimental studies nanofluids behave like a single phase Newtonian fluid in convectional heat exchange process [3–6]. Recently in literature [1,5,6] was presented develop of methods based on large number of experimental data, uses to determine nanofluids thermophysical parameters. These correlations provide theoretical and practical analysis of heat exchange due to natural convection. Paper [2] analyses the process of steady natural convection in nanofluid in the vicinity of a vertical plate heated by constant heat flux. In particular water suspension of Al_2O_3 and CuO was analysed. Volume fraction of these suspensions did not exceed 10%. Similar work [3] described natural convection in water suspension of Al_2O_3 with the same thermodynamic conditions. Another paper [4] describes numerical solution of equations of conservation of mass, momentum and energy in natural convection process in water suspensions of Al_2O_3 placed in a Γ shaped enclosure.

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Due to miniaturisation of heat exchange devices, micropolar fluids as refrigerant or heating media are also analysed in literature [7–9]. A useful model of micropolar fluid is a model proposed by Eringen. This model takes into account fluid microrotation [7–9].

Theory of micropolar fluid can be used to describe many types of fluid such a liquid crystal, polymeric fluids, suspension solution, lubricants, animal blood etc.

The aim of this study is to evaluate cooling intensity of the heated vertical plate. The plate is heated by sudden rise of heat flux q_0 in time $\tau = 0$. Vertical plate is cooled by micropolar fluid containing nanoparticles. The considerations take into account unsteady heat exchange process in natural convection in micropolar fluid. The properties of nanofluid change after addition of $Al_2\ O_3$ or Cu nanoparticles with different size.

2. Estimating properties of nanofluids

The typical approach used to study thermodynamic properties of nanofluids is based on assumption that nanofluids behave like single phase fluids. There are empirical equations proposed by authors used to determine different features of nanofluids such as thermal conductivity, viscosity, density and thermal expansion [5,6]. It is worth mentioning that all models are applicable only in specific range of nanofluid parameters.

Several authors are proposing different methods to estimate heat conductivity of nanofluid. This parameter is the most important with respect to the heat transfer process [5,6]. Based on large amount of data presented in Refs. [5,10] a method of heat conductivity calculation was proposed:

$$\lambda = \lambda_f + 4.4 \cdot Re^{0.4} \cdot Pr_f^{0.66} \cdot \left(\frac{T}{T_{fr}}\right)^{10} \cdot \lambda_f \cdot \left(\frac{\lambda_s}{\lambda_f}\right)^{0.03} \cdot \varphi^{0.66} \tag{1}$$

Equation (1) is suggested especially when nanofluid is based on water and ethylene glycol with $Al_2\ O_3$, TiO_2, CuO or Cu nanoparticles and has wide range of applicability [1]. In equation (1) Reynolds number is given by equation:

$$Re = \frac{2 \cdot \rho_f \cdot k_b \cdot t}{\pi \cdot \mu_f^2 \cdot d_p} \tag{2}$$

and Prandtl number is:

$$Pr = \frac{\mu_v \cdot (c \cdot \rho)}{\lambda \cdot \rho} \tag{3}$$

Recently, using large amount of experimental data from many authors, an empirical equation to determine dynamic viscosity has been proposed [5]:

$$\mu_v = \frac{\mu_f}{1 - 34.87\left(d_p / d_f\right)^{-0.3} \cdot \varphi^{1.03}} \tag{4}$$

To calculate the equivalent diameter of a base fluid molecule from equation (4), an equation proposed by Ref. [5] was used:

$$d_f = \frac{6 \cdot M}{N_A \cdot \pi \cdot \rho_{f0}} \tag{5}$$

One of the methods to determine density, heat capacity and thermal expansion coefficient is the conventional approach [5,6]. It can be assumed that nanofluid is a single phase fluid. Thus those parameters can be calculated as in case of mixtures. It is given by:

$$\rho = (1 - \varphi) \cdot \rho_f + \varphi \cdot \rho_s \tag{6}$$

$$\rho c = (1 - \varphi) \cdot (\rho c)_f + \varphi \cdot (\rho c)_s \tag{7}$$

$$\rho \beta = (1 - \varphi) \cdot (\rho \beta)_f + \varphi \cdot (\rho \beta)_s \tag{8}$$

In energy equations, heat capacity and thermal expansion coefficient are always considered with fluid density, thus equations (7) and (8) will be used.